## Case Studies

# Automobile Air Conditioning: A Case Study of CFC Replacements

Part II
Part I: Fire Extinguishers (LCA 2 (3) 135-140 (1997))

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## Abstract

Global warming impact (GW) of automobile air-conditioners using two refrigerants – a hydrocarbon blend and HFC-134a – were estimated and compared. The HFC-134a system showed a GW 20-90% greater than that of the hydrocarbon system. Volatile organic compounds (VOC) emissions of the air-conditioners were near to equal, in the basecase scenario slightly higher for HFC-134a, in some scenarios slightly higher for the hydrocarbon.

**Keywords:** Automobile air-conditioners, HFC-134a; automobile air-conditioners, hydrocarbon blend; automobile air-conditioners, refrigerants; chlorofluorocarbons; global warming (GW); GW; refrigerants, HFC-134a; refrigerants, hydrocarbon blend; TEWI; total equivalent warming impact (TEWI); VOC; volatile organic compounds (VOC), emissions, air-conditioners

## 1 Introduction

Replacement of CFCs is a subject of great technical, commercial and environmental interest. From an environmental standpoint, a key question is: *How can global warming be minimised as CFCs are replaced?* With this question in mind, the authors examined one important sector of CFC replacement, automobile air-conditioning. We compared the global warming impact (GW) of two refrigerants in a conventional Rankine-cycle vapour-compression air-conditioner. One refrigerant is HFC-134a, which has been introduced widely as a replacement to R12 in automobile air-conditioning (A/C). The other is a hydrocarbon blend. Hydrocarbons are established commercially in refrigeration in Europe. In A/C, while technically proven, they have yet to achieve commercial acceptance.

The comparison was done using the principles of Life Cycle Assessment, ie a quantitative summation of relevant emissions throughout the life cycle and a comparison on the basis of an equivalent functional unit. The life cycle systems (defined for each application) represent estimated typical practice in the UK, but the general results of the comparison are valid for many other locations where the two refrigerants compete.

Global warming emissions were summed for the life cycle of each system, normalised according to the functional unit, and weighted according to recognised global warming potential factors [UNEP, 1995], which reflect the potential global warming capability of the substance relative to carbon dioxide. Emissions of volatile organic compound also were quantified and compared.

## 2 Methodology of the Study

The methods used in this study are consistent with state-of-the-art practice of Life Cycle Assessment (LCA) as articulated in SETAC publications and other technical literature and noted in the preceding article of this series [JOHNSON et al., 1997]. This study is a horizontally-limited LCI/LCA, in that it includes only two impact categories: global warming and photochemical ozone formation (related to VOC emissions). It is vertically complete, in that it extends from cradle to cradle. This distinguishes it from most studies of total equivalent warming impact (TEWI), which usually do not include production of the refrigerant fluid.

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### 2.1 Definition of applications and functions

The application examined in this study is an automobile air-conditioner. This application is well-known; its function is understood clearly – to keep the contents of the car cool. In both applications, either refrigerant considered – HFC-134a or the HC blend – works according to the conventional technology of vapour compression and liquid evaporation. Both refrigerants studied have been proven technically in both applications considered. The traditional refrigerant for these applications was R12, which is subject to phaseout under the Montreal Protocol. Many cars on the road still have R12 in their A/C systems.

### 2.2 Functional unit

For this application, the functional unit used for the LCA comparison is defined as a typical family passenger car in the UK. The level of cooling output is assumed at 7 kW, estimated by researchers at Oak Ridge, after discussions with automobile manufacturers, and used in subsequent studies [Fischer et al., 1991; Fischer et al., 1994; Fischer, 1995]. The function of the A/C is assumed to be the same for each refrigerant, which is verified by surveys showing that typical drivers do not know which refrigerant is being used [Rolotti, 1995].

### 2.3 System boundaries and scope

The general scope and methods of the study have been defined in a preceding article of this series [Johnson et al., 1997]. The same allocation rules and impact factors have been used. Emissions of volatile organic compounds (VOCs) were not weighted by compound; they simply were summed by mass. One subsystem not included is the A/C hardware. A cursory examination shows that it would account for less than 5% of the relevant inventory; also, it is essentially the same for each refrigerant being compared.

## 3 Definition of the Life Cycle System

The application examined in this study is air-conditioning in a UK passenger car, sold in the beginning of 1996 and scrapped at the end of 2006, and driven a UK-average of 14 650 km per year [British Refrigeration Assn, 1996]. Air-conditioned automobiles account for 15-20% of new sales and approximately 10% of the national fleet in the UK. By 2000 they are projected to account for 25% of new sales and 15-20% of the national fleet [Simpson, 1995].

The life cycle system comprises the following stages: manufacturing, installation, usage (including refilling) and disposal. The main *material inputs* are the refrigerant and its precursors. *Energy/transport inputs* are concentrated in the use phase of the life cycle. The definitions most significant to the study's question are: efficiency of the A/C, refrigerant leakage and exhaust emissions of the automobile.

In this section, subsections A-E describe the inputs and outputs of the life cycle system in greater detail and reference the sources used to compile them. Subsections A-C cover Installation, Usage and Disposal, subsection D covers Production of Agent and subsection E covers Energy and Transport Modules. Results of the GW/VOC comparison of HFC-134a and the hydrocarbon blend are presented in section IV. Data used in defining the system are the best available at present. They represent current practice, which, it is clearly recognised, may vary considerably in individual cases. All figures, unless otherwise noted, refer to those used in the base case analysis. For most of the life cycle system, data was sourced from public-domain technical information, much of which is referenced in the endnotes. For the manufacture of HFC-134a, the primary source of data was a study by Professor R.E. Banks and Dr P.N. Sharratt of University of Manchester Institute of Science and Technology [Banks and Sharratt, 1996]. This was conducted expressly for this comparison, and is based on research of the relevant patent and technical literature as well as regulatory submissions.

### 3.1 Installation

An automobile A/C is purchased on a turnkey basis as an accessory to the automobile. The manufacturer typically designs, procures equipment for, installs and then commissions the system. The significant material input is the refrigerant itself. The average charge for a HFC-134a system in the UK is 0.8 kg, for a hydrocarbon blend is 0.4 kg [Simpson, 1995]. On average, an additional 10% is leaked to atmosphere upon installation [Simpson, 1995].

### 3.2 Usage

Key parameters of the use phase (→ *Table 1*) have been compiled from government and industry sources. The most significant factors – efficiency of the A/C and refrigerant leakage – are discussed in the *subsections 3.2.1 - 3.2.2*

#### 3.2.1 A/C Efficiency

Efficiency of refrigeration (i.e. the ratio of energy input to cooling output) is a complex function in practice, comprising many different variables. For a generalised comparison like this, a number of these variables must be assumed as constants. (Otherwise one ends up with a very specific comparison, which was not this study's objective.) In the A/C case, we have used the model of efficiency developed by Oak Ridge National Laboratory [Fischer, 1995] in its investigations of TEWI. Assumed as constants are the cooling load, the A/C circuit's temperature profile, efficiencies of the car's motor and the A/C compressor and the losses of power to

Table 1: Key parameters of the use phase, basecase

| Parameter | Quantity | Source |
|---|---|---|
| Engine efficiency | 25% | [FISCHER, 1995] |
| Incremental fuel use | 0.057 litres gasoline/tonne km | [FISCHER, 1995] |
| Cooling capacity | 7 kW | [FISCHER, 1995] |
| Evaporating T | 4.4 C | [FISCHER, 1995] |
| Condensing T | 65 C | [FISCHER, 1995] |
| Annual A/C usage | 88 hours | [FISCHER, 1995] |
| Refrigerant leakage | 10% per year | [SIMPSON, 1995; FISCHER, 1995] |
| Refrigerant refills | 1, at 6 years | [British Refrigeration Association, 1996] |
| Annual vehicle usage | 14 650 km | [British Refrigeration Association, 1996] |
| Lifetime | 11 years | [British Refrigeration Association, 1996] |

auxiliary equipment. The only variable is the refrigerant's isentropic COP. At the conditions specified by Oak Ridge [FISCHER, 1995], the operating COPs of HFC-134a and the hydrocarbon blend, respectively, are 1.768 and 1.804.

### 3.2.2 Refrigerant leakage

The UK Department of the Environment has estimated officially refrigerant leakage from mobile A/C [UK Department of the Environment, 1996]. Estimated as a fraction of the existing charge, annual leakage historically has averaged 30% and its future potential is 10%. Other estimates for the UK fall within this 10-30% range [FISCHER et al., 1991; SIMPSON, 1995; Rover Group UK, 1996; Volvo Car Corporation, 1996; AEA Technology UK, 1996], none of them as low as 10%. In the basecase analysis, a leakage rate of 10% per annum has been assumed in the use phase.

## 3.3 Disposal

The UK Department of the Environment has estimated officially the refrigerant disposal loss factor from mobile A/C [UK Department of the Environment, 1996]. Estimated as a fraction of the remaining charge, emissions to atmosphere upon disposal historically averaged 100% and their future potential is 25%. Other estimates for the UK fall in this 25-100% range, none of them nearly as low as 25%.

Regulations require the recovery of (non-CFC as well as CFC) refrigerant, but there is little economic incentive to do so. In automobiles, refrigerant quantities are relatively small, and capital costs of recovery equipment are relatively high [WELLS, 1995].

In the basecase analysis, a disposal emission rate of 25% has been assumed.

## 3.4 Production of agent

Two sub-systems have been defined for the production of refrigerant. In each sub-system, relevant atmospheric emissions have been estimated.

### 3.4.1 HFC-134

Also referred to as R134a, its chemical name is tetrafluoroethane. It is produced commercially by a number of companies worldwide. In this study, the production route used by ICI, a major supplier to the UK market, was modelled. Parts of the process route to this compound are proprietary; these were estimated through review of patents, technical literature and regulatory submissions [BANKS and SHARRATT, 1996].

### 3.4.2. Hydrocarbon blend

A blend of propane and isobutane. These are very common gas liquids, produced as byproducts of oil and gas production and as co-products of oil refining. The production routes are well-known and documented in the public domain.

## 3.5 Energy and transport modules

These modules are used to convert energy/transport inputs to the system into emissions. The main energy/transport module in this study is the automobile's engine, assumed to be a gasoline one. Engine's efficiency (lower heating value input of the gasoline to energy output) is assumed at 25% [FISCHER, 1995].

Because exhaust emissions are very significant with respect to GW and volatile organic compounds (VOC), several datasets were examined [INFRAS, 1995; MORIGUCHI et al., 1996; EU Directive 94/12/EC; ERIKSSON et al., 1995]. The final dataset [ERIKSSON et al., 1995] was chosen, because:

(1) it is based on physical measurements of an actual population;

and

(2) about 80% of this automobile population are equipped with three-way catalytic converters.

This corresponds roughly to the UK automobile population in the period studied.

## 4 Comparison of the Refrigerants

Using the definitions of *Chapter 3* and the methodology described in *Chapter 2*, the GW and VOC emissions of the HFC-134a and hydrocarbon systems were compiled. In the basecase scenario, the HFC-134a system has a 30% greater GW than the comparable hydrocarbon system (→ *Table 1*). The main cause of the GW difference is emissions of HFC-134a. Of the 30% gap, 2% is a result of efficiency differences (as a comparison of the COPs would suggest), the remaining 28% comes from leaks.

VOC emissions are negligibly higher for the HFC-134a system. VOCs are roughly equal, because emissions of the hydrocarbon refrigerant (itself a VOC) are matched by VOCs in the additional engine exhaust of the HFC-134a system. Because there is an inherent level of inaccuracy and imprecision in studies such as this, three alternative scenarios to the base case were computed to test the robustness of the conclusion. It has been concluded that the basecase result holds; indeed the GW difference of the two systems is probably greater than in the basecase.

In the three alternative scenarios (assumptions presented with the results in *Table 2*), the most significant factors were varied within their estimated ranges:

*High Leakage.* The annual leakage is increased to 30% (thus requiring five refills) and disposal recovery is estimated at 20%. The authors believe this scenario is the most accurate reflection of current practice. GW is 92% greater for the HFC-134a system.

*Low Leakage.* The annual leakage is reduced to 5% and disposal recovery is estimated at 75%. This would probably reflect best practice worldwide (although some would argue a 95% disposal recovery is possible). GW is 22% greater for the HFC-134a system.

*Less Driving.* The average driving distance in central Europe is 12000 km [Fischer et al., 1994]. GW is 37% larger for the HFC-134a system, because the impact of refrigerant emissions is proportionately greater.

## 5 Conclusion

The conclusion is the HFC-134a system showed a GW 22-92% greater than the hydrocarbon system. This represents a GW difference of up to 8% over the lifetime of automobiles [Moriguchi et al., 1996], which are major contributors to global warming.

The relevance of this difference in the UK grows as A/C becomes more common in automobiles. By 2000, about 25% of new cars in the UK will have A/C [Simpson, 1995]. The relevance in warmer parts of the world is undisputed. Some 80% of North American and 85% of Japanese cars are equipped with A/C [Fischer et al., 1991].

VOC emissions of the air-conditioning systems were nearly equal for the two refrigerants, in some cases slightly higher for HFC-134a, in others slightly higher for the hydrocarbon.

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**Table 2:** Parameters of alternative scenarios

| Parameters (Assumptions) | | Scenarios: Base | Leakage: High | Leakage: Low | Less Driving |
|---|---|---|---|---|---|
| Leak in Filling, % of charge | | 10% | 10% | 10% | 10% |
| Agent Charge, kg | | | | | |
| | 134a | 0.8 | 0.8 | 0.8 | 0.8 |
| | HC BLEND | 0.4 | 0.4 | 0.4 | 0.4 |
| Leaks, annual % | | 10% | 30% | 5% | 10% |
| Refills, number of | | 1 | 5 | 1 | 1 |
| Disposal Recovery, % | | 75% | 20% | 75% | 75% |
| Annual A/C usage, hrs | | 88 | 88 | 88 | 72 |
| Annual vehicle usage, km | | 14650 | 14650 | 14650 | 12000 |
| Results, GW (ktonnes CO2 equivalent) | | | | | |
| HFC-134a | | 5854 | 8612 | 5469 | 5026 |
| Hydrocarbon blend | | 4488 | 4491 | 4487 | 3676 |

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# LCA Tools for Decision Support: Chainet

## European Network on Chain Analysis for Environmental Decision Support

### What is CHAINET?

CHAINET is a EU-supported Concerted Action in the Environment and Climate Programme. Similar to its predecessor LCANET, it is a European network which seeks broad participation. CHAINET addresses the use of a variety of environmental tools. The Concerted Action commenced in Decemer 1997 and will run for two years.

### Aims

The aims of CHAINET can be condensed to:

- linking the different scientific tool communities, problem owners and stakeholders,
- establishing a toolbox for chain analysis, linking demand for environmental information with supply of relevant information,
- investigating how tools can be applied in three selected cases to suggest specific directions for design and development.

### Organisation

CHAINET has a Board with members from eight different European institutes. The Board has the final responsibility with respect to all activities. From CML Prof. Helias A. Udo de Haes is chairman of he Board and Nicoline Wrisberg is the coordinator. Some of the Board members are responsible for organising a workshop or a meeting, while the overall coordination of CHAINET's activities is the responsibility of CML. Working groups will be set up for each of the three cases. These working groups are open for all interested.

### Work-Programme

#### The toolbox

The supply of tools providing environmental information for decision support is large and diverse. In a problem-oriented approach, distinct demands for environmental information according to the different decision contexts will be the starting point. These demands will be linked to relevant tools or combination of tools. A so-called toolbox will be established consisting of guidelines linking demands for environmental information with supply of environmental information (tools).

#### The cases

Three cases have been selected as useful vehicles for discussions on how tools can be applied in order to obtain information on net environmental improvements. The three cases are the supply, use and waste management chain for

- automobiles,
- consumer electronic goods,
- domestic clothes washing.

The working groups, one for each case, will

- identify environmental problems in the chain,
- describe the state-of-the-art results from existing environmental analyses,
- discuss relevant tools for the analysis of environmental impact,
- formulate guidelines for the application of tools.

### What will be the main results?

- A guidebook for analytical tools for decision support in design and comparison,
- a network of environmental problem owners nd experts on environmental tools.

### CHAINET Activities

The objectives will be achieved through the organisation of meetings (network meetings and workshops), establishment of a homepage on the internet and composing reports in interaction with CHAINET members.

#### Network meetings

An inaugural meeting has been held at Windsor (near London Heathrow) on May 26, 1998. The final network meeting will be held in Dresden, Germany, in the first week of October 1999.

#### Workshops

Workshops on the application of tools in each of the three cases will be held in Noordwijkerhout, the Netherlands, on October 29-30, 1998 and in Sevilla, Spain, on March 25-26, 1999.

#### Homepage and newsletter

A homepage has been established, which will provide information on the CHAINET activities:
**http://www.leidenuniv.nl/interface/cml/chainet.hp22.htm**
It will be updated once every two months. An electronic newsletter will be issued four times during the project period.

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